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Iron redox battery as electrical energy storage system in the Spanish energetic framework

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ABSTRACT

The energy storage technologies will play a crucial role in the near future under the use of efficient electric energy sources and renewable energies such as wind and solar energy. This sort of energy usually suffers from intermittent problems in distributed generation systems. To overcome this problem, electricity storage systems provide solutions to improve dispatchability and reliability. The different electrochemical storage systems are presented when considering their applications and comparing advantages and disadvantages. Based on this description and the possible applications of each technology, a particular case is considered in the framework of the Spanish energetic system. An iron redox battery (one of the most promising technologies) is analyzed from an economic point of view determining important aspects as the payback of the investment or the IRR.

Introduction

General scope

The energy situation in Europe is determined by measures to reduce the CO_2 emissions and the dependence on fossil fuels from other countries. For these reasons, the energy production from renewable sources becomes especially important. However, the large energy distribution leads to a benefit for the renewable energy which will be unviable without an appropriate storage capacity system.

The produced energy from renewable sources has the advantage of not emitting CO_2 to the atmosphere. Renewable energy allows managers to use local energy sources and to reduce the energy dependency on foreign energy sources, especially fossil fuels, which are mostly imported to Spain and the European Union [1]. Therefore, one of the main objectives of European Authorities is to increase the use of renewable sources in energy production. On March 9, 2007, the Spring European Council, with the support of the European Parliament and the Member States agreed that at least 20% of its energy consumption must be produced with renewable energy sources by [2]. Nevertheless, the energy situation of each specific European country must be taken into account. The European Council also adopted a commitment to reduce by at least 20% its greenhouse effect gases emissions to achieve energy savings of 20%. Furthermore, biofuels reach 10% within fuels consumed in the EU transport. In this sense, Spain was encouraged to reduce exactly 20% of its energy consumption.

Renewable energy integration in the whole energy system

It is recognized that the energy production and consumption as known nowadays is not sustainable. It means that, fossil fuels could be finished in the long term besides the threat which supposes its use for the environment, mainly due to greenhouse effect gases emissions and its impact on climate change [3,4]. This is why, industrialized countries are supporting and legislating new technologies to ensure that their energy will be sustainable in the future. This sustainability aims to maintain the economical growth of the country while increasing energy security and environmental protection.

The renewable energy sources and its application, especially to produce electricity, have been supported by all the Governments of Spain. In 2011 the Renewable Energy Plan 2011–2020 (or 20-20-20 package) was published to indicate the commitment of the Spanish Government to cover at least 20% of total primary energy consumption by renewable energy sources in 2010 [5].

Nevertheless, it is still a long way to reach the target rates set in 2020 regarding the proportion of renewable energy in final energy consumption. The power sector has to greater contribute to achieve this goal in the case of Spain [7]. According to recent studies carried out by the Spanish Government, 40% of renewable energy source is required in the power (electricity) sector to reach

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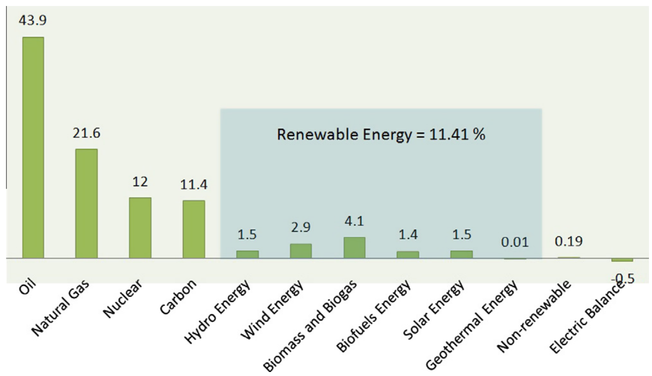

Fig. 1. Primary energy sources, the case of Spain. Adapted from (IDAE [6]).

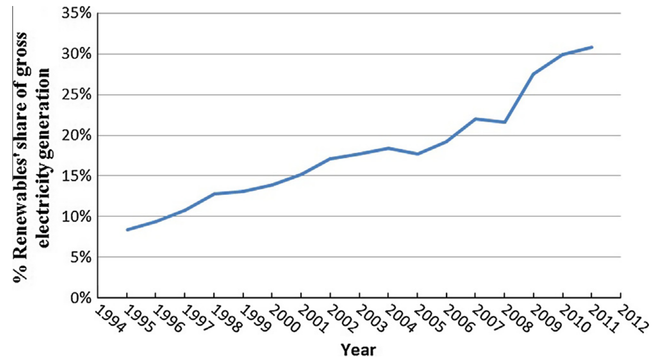

Fig. 2. Renewables' share of gross electricity generation. *Source:* ForoNuclear.org [15].

a renewable energy integration of 20% in the whole system. To achieve this desirable goal is not easy. While fossil fuels can be easily transported and can perform as energy stores, most of renewable energy sources cannot be stored or transported without being converted first to electricity [8]. This is why, energy storage strategies and technologies are necessary to contribute to sustainable development [9]. It is necessary to store energy when it is produced by renewable sources (such solar and wind power) to be consumed when required. Nowadays, there are many storage systems [10]. However, its industrial implementation and regulations [11] are still being under development. It is very important to have a positive balance between benefits obtained from the use of storage systems compared with the economical investment [12]. In this contribution a simplified analysis about one of these new storage devices is presented: the Electro-Chemical Energy Storage Semi-Redox Iron Flow. The aim of the study is to quantify the functionality and the economical viability of the storage device in the Spanish energy scope (see Fig. 1).

The need to store energy

The uncontrollable nature of some renewable energy sources leads to increase the difficulties to safely operate power systems. This kind of energy will represent a significant percentage of the power installed capacity in the future. Electricity generation from renewable sources does not firmly contribute to the power supply warranty. Nevertheless, it contributes to cover the power demands in terms of annual energy supply. This lack of power guaranteed is a problem for the operation of the power system because it requires a stable power generation. Additionally, there are problems associated with the particular renewable energy generation and problems of network congestion in areas with high consumption and low generation rates, due to the saturation of the transmission lines.

The extent of regenerative electricity involving a disparity between power production and consumption can lead to the loss of electricity produced if the presence of electricity storage systems is not ensured. Every country has its own necessities of storage systems related to the precedence of the energy in the national system, as the case of Japan [13] or Saudi Arabia [14,4]. The growing of renewable energy in Spain [15] is considered in all the forecasted scenarios (Fig. 2).

Electricity storage systems

Worldwide electrical grid storage capacity is about at 127 GW and it increasing each year [16]. Electric Energy Store Systems (EES) are crucial for future developments in national energy grids [17]. In general, an energy storage system is more than ever a necessity [18,19] and many different sorts of devices can be applied to storage electricity [20,21]. This necessity increases as the use of renewable energy gets more important in national balances of electricity [22]. Economic implications of these devices attract great interest in recent times [23,24].

Two categories of EES can be considered related to their applications [25]: Energy Management applications (long-duration discharge applied to decouple generation and consumption of electric energy), and Power Management Applications (short duration discharge applied to deliver power in real time).

Energy Management applications involve different scales of time, since daily up to several times per month along a year (long duration storage up to hours or more). Power Management Applications involve short-duration with a big number of discharges over a year involved (short fractions of time up to some minutes).

An overview on the more efficient electrochemical storage systems batteries

Electrochemical batteries are one of the most used technologies for store energy [26].They are very convenient for many sort of uses and adaptable to grid necessities providing very good efficiency, in some cases up to 95%. Different technologies have been developed in the recent years [14]: Lead-acid batteries, Sodium/Sulfur batteries and Flow batteries, Nickel–Cadmium and Lithium Ion. Apart of them, the Iron flow battery will be presented in this article as one of the most interesting ones based on economic and technological factors. A short description of the general types of batteries is provided (see Fig. 3).

Lead-acid batteries

These are the oldest and most mature battery technology currently in use. These battery cells consist of spongy lead anode and lead acid cathode immersed in a dilute sulfuric acid electrolyte, using lead as the current collector [27].

Sodium/Sulfur batteries

Sodium/Sulfur (Na/S) batteries are based on a high-temperature electrochemical reaction between sodium and sulfur separated by a beta alumina ceramic electrolyte. The active materials in a Na/S battery are molten sulfur as the positive electrode and molten sodium as the negative one [28].

Nickel Cadmium batteries

Nickel Cadmium (NiCad) batteries are a rechargeable batteries using nickel oxide hydroxide and metallic cadmium as electrodes. Sealed Ni-Cd batteries require no maintenance, as described on [29].

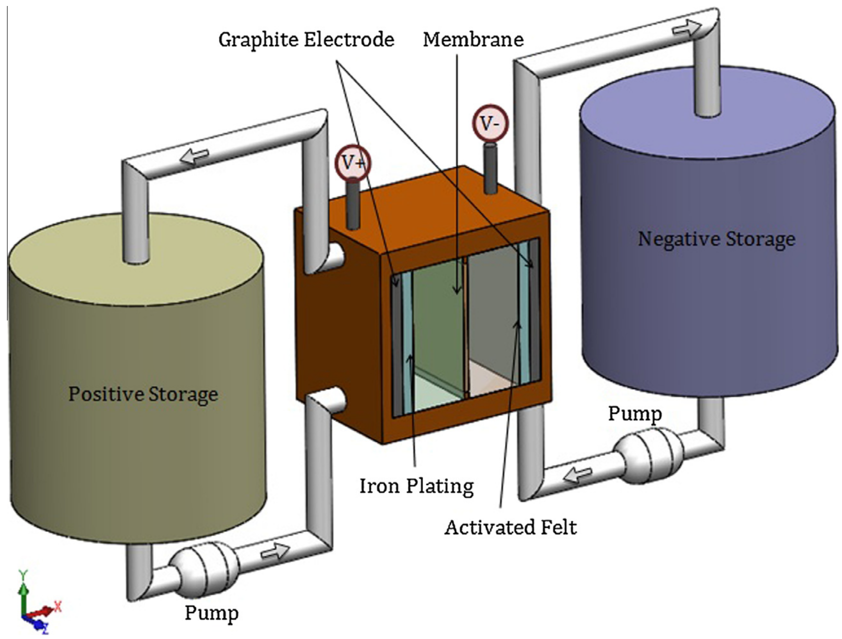

Fig. 3. Typical battery scheme.

Lithium Ion batteries

Lithium Ion (Li-ion) batteries are batteries where the cathode is a lithiated metal oxide and the anode is made of layers of graphitic carbon. Lithium ions move between the anode and cathode to generate current flow. At the carbon anode the lithium ions combine with external electrons and they are deposited between carbon layers as lithium atoms. This process is reversed during discharge [30].

Flow batteries

Flow batteries are electrochemical devices that convert chemical energy into electrical energy during battery discharge and, during battery charge, batteries convert the electrical energy back into chemical energy for long-term storage [31].The fundamental building block of a battery is a single electrochemical cell. Cells are connected together in variety of configurations to provide the necessary voltage, energy and power for their application [32,33].

Every cell has two separate chemical reactions occurring—one involving the release of the electrons during battery discharge (at the negative electrode material, or anode) and one involving the take-up of the electrons during battery discharge (at the positive electrode material, or cathode). When the cell is charged the electrochemical reactions occur in the reverse directions, taking electrons out of the material at the positive electrode and putting them back into the negative electrode material.

Electrolyte solution is crucial, as it allows balancing of the negatively charged electron that is moving from one electrode to the other. The materials in redox batteries (electrolyte, positive and negative electrode materials) are housed in a separate container and they are actively pumped into the container where the electrochemical reactions occur.

The first class of electrolyte batteries appeared in the 70 s. The first batteries were made in Zinc as anodic material, combined with Oxygen, Chlorine or Brome. In 1974 Thaler proposed the actual redox prototype [34]. In 1980 Hagedorn [35] published the first results obtained on prototypes. Since then, different cell prototypes have been proposed highlighting redox batteries of Fe/Cr [36].

An interesting summary of the redox battery is presented in Weber et al. [37] who highlighted this main idea: the future of this technology goes through optimizing the design modeling: flow and transport.

Different sort of flow batteries can be found used as accumulators depending on the nature of the electrolyte:

– Vanadium redox batteries (VRB). VRB store energy by employing vanadium redox couples dissolved in mild sulfuric acid solutions (electrolytes). Hydrogen ions are exchanged between the two electrolyte tanks through a hydrogen-ion-permeable polymer membrane along charge and discharge processes [38–40].
– Zinc/Bromine (Zn/Br) batteries. In each cell of a Zn/Br battery there are two cells of a Zn/Br battery with two different electrolytes flow past carbon–plastic composite electrodes in two compartments separated by a micro porous polyolefin membrane.
– Iron redox batteries (FeRB). This is the new type of battery proposed in this contribution. It uses a ferrous chloride salt in aqueous solution with ammonium chloride as the supporting electrolyte. On the negative side of the battery, ferrous ions are reduced during charge, plating as iron metal onto a graphite electrode. On the positive side of the battery, ferrous ions are oxidized to ferric ions during charge, remaining in solution. These reactions are the opposite upon discharge. To preserve electroneutrality, chloride ions ($Cl-$) travel across the micro porous membrane separator in the opposite direction as the electrons [41–45].

Assessment and comparison of the electrochemical energy storage technologies

Power and energy storage technology are the essential difference in each energy storage technology. These capacities are key indicators of what applications a medium storage might be able to fulfill. Efficiency and cycle life are other two of the most interesting aspects to be considered before and along selecting a storage technology. Both of these parameters affect the overall storage cost. Low efficiency increases the effective energy cost by diminishing the performance of the whole system. Low cycle life also increases the total cost, as the technology needs to be replaced

Table 1
Energy applications for different electricity storage systems. Adapted from Chen et al. [8].

Technology	Power rating	Discharge time (second, minute and hour)	Cycle life to 80% DOD	Efficiency (%)	Capital cost		Advantages	Disadvantages
					Current cost $/kWh	Future cost $/kWh		
Lead acid	0–20 MW	s–h	600–500	70/80	100–150	100	Low cost, spill resistant (Sealed batteries) Useful for automobiles No liquid parts	Limited low temperature Performance Cost and cycle life
NaS	50 kW–8 MW	s–h	2000	80/90	500	500	High energy and power density Relatively high efficiency Long cycle life Relatively well-established	Relatively expensive (still small volume manufacturing) High temperature produces unique safety issues
NiCd	0–40 MW	s–h	2000	60/65	300	300	Excellent cycle life Flat discharge curve Good high- and low temperature performance High resistance to shock and vibration	High initial cost Only fair charge retention Memory effect
Li-ion	0–100 kW	m-h	1200	85/90	600	250	Limited high-rate capacities; safety concerns	High initial cost, relative high rate of self discharge
VRB	30 kW–3 MW	s–10 h	10,000	75/85	1450	1000	Do not directly engage electrodes in the electron transfer process nor involve them in solid–state reactions. Neither energy storage nor power capacity is dependent on their dimensions. can be stored indefinitely at any state-of-charge with only negligible self-discharge	High initial cost Base do not raw materials
ZnBr	50 kW–2 MW	s–10 h	8000	75/85	300	100	High energy density in small cells Flat discharge rate	Dries out quickly Cannot be stored for more than 2 months when charged
FeRB	30 kW–3 MW	s–10 h	10,000	75/85	1130	850	Can be stored indefinitely at any state-of-charge with only negligible self-discharge Almost unlimited cycles Cheap an widely available starting materials	Energy storage and power capacity not independent

more often. Both parameters should be considered together in the economic balance of the investment in this storage technology, to compare different possible choices.

Furthermore, every device is more suitable to different applications: most technologies are not practical or economical suitable for both power and energy applications. Table 1 shows the suitability of some of the described technologies for electrochemical energy storage applications [10]. It can be observed than the FeRB battery has the same advantages than VRB but with a lower capital cost.

Electricity storage systems benefits

The benefits of the electricity storage systems must be considered as a whole: energy operation and economic sustainability [46]. The basic question to be examined is whether the investments will be recovered. In this case, to analyze the return, a particular case of Flow Iron battery of 3 kW and 21 kW h is presented, in the framework of the Spanish electric system, with an initial cost of 13,352.15 €.

Operational benefits

Apart from an economic analysis, the benefits in the operation of a national electric system of the storage devices are important: The final objective is the integration of the renewable sources of electricity generation. They are experiencing dynamic growth but are also subject to relatively strong fluctuations. Some of these benefits are here detailed.

– Support for renewable energy. The electricity storage system can reduce fluctuations in power output of wind and photovoltaic installations allowing dispatchability.
– Reliability and quality of supply.
– Active and reactive power control. The power interfaces provide the ability to change rapidly between active and reactive power absorbed and/or assigned to the network.
– Load leveling. The electricity storage devices are recharged during off peak periods using lower-cost energy generation plants from base and are downloaded during periods of high demand improving the load factor of the whole system.
– Load following. The electricity storage devices can accept changes in demanded power level very quickly.
– Help in the Energy Management.
– Tertiary reserve.
– System stability. Power and frequency variations are attenuated more rapidly varying output active or reactive power in the system.
– Automatic control in the generation. The stored energy in the system can be used for minimizing the area control error.
– Reducing the use of fossil fuels to improve overall system efficiency.
– Reduction of transmission and distribution losses if the location of the storage system is optimized against the consumption points.
– Increased efficiency and reduce maintenance of plants carrying the machines operating points with lower variation around its optimum performance.

Economic benefits

To analyze the feasibility of these elements, the need is justified as part of an energy system that seeks to optimize the use of renewable energy, an Iron Flow battery is presented as electricity storage efficient system, introduced in Table 1 as one of the most convenient among all the considered examples.

Time-shift

Storage can be used to time-shift electric energy generated. Users are able to buy and sell the energy. Usually it is stored when demand and price for power are low, so the energy can be used when power demand and price are high. Those who invest in this kind of battery receive the benefits of this previously explained concept.

Load following

This service, individually provided by each one of the batteries has a benefit for the global electricity system as a whole. Since this concept reduces the need for human resources dedicated to the management of the system, thus reducing the risk of human failure and endowing it with flexibility in excess or in default of electrical generation.

Spinning reserve

Another service provided by batteries with active management is acting as storage generators to face unexpected demand changes or unexpected mistakes in the generation of alternative energy sources.

Integration of not controllable power sources: nuclear and renewable

The not controllable sources of energy are those that receive the benefit of an implantation of batteries allow the not controllable sources still growing. Moreover, this system also facilitates its management as it has the capacity of becoming automatic and allowing a greater input of renewable. These two aspects are very positive as they guarantee a gradually stabilization of the energy cost.

Regulation of power

This service is constantly adapting energy changes to offer and demand profile. The frequency is the indicator of the balance condition between offer and demand where values over 50 Hz (for the EU) indicate an excess of offer and values under 50 Hz represent an excess of demand.

Compensation for reactive power

The electrical engines inject reactive energy to the grid. This type of energy is not useful, it is a disturbance that loads the grid, occupies it, prejudices the main energy use and it is penalized by the electrical companies. The most extended solution to avoid this kind of penalization is to transform this useless energy into a useful one by means of AC/DC reversible transformers, that is to say, make it pass through a battery system. The owner of the accumulator obtains benefits from three main concepts:

– The user is able to avoid the penalization for the reactive energy generated in its facilities.
– The user decreases costs by making the most of the recovered energy and by decreasing the quantity purchased.
– The user will be rewarded with a cleaned grid by the action of consuming the reactive energy of the grid.

Case study: Iron flow battery analysis in the Spanish energetic framework

The Spanish electricity system recognizes the need of introducing efficient storage energy systems. This is crucial to integrate renewable energy sources into the whole system. Therefore, different strategies are being used in order to achieve this storage.

The electrical energy can be generated, transported and easily processed. However, it is difficult to store it in large quantities. But, even if it is complicated, the Spanish electricity system accepts various methods of energy storage along the supply chain:

- Big scale (GW): reversible hydro-electrical (Pumped Hydro Energy Storage, PHES)
- Grid storage and final user (MW and KW): batteries, capacitors, superconductors and flywheels.

New energy storage technologies will become key elements of the future electrical systems so that, the electrical storage can add value to the chain of electricity supply. Particularly, Iron flow battery is an economic and robust alternative in the MW and KW scale. It is a promising solution as it is one of the most durable and reliable batteries.

The renewable energy storing not only covers the gaps between supply and demand, it also allows households to consume their own generated electricity and sell the surplus to the network. In the case of the Spanish legislation, this Iron flow battery technology will be applied to grid storage systems. Nowadays, this technology is very new but, as here depicted, it is a real future alternative.

The current law estimates that the percentage from renewable energies in Spain (especially in wind and solar energy) that need to be stored and regulated would be 4.4% of the total energy. In this grid store systems, the Iron redox batteries must play a key role.

In this section the economic balance of each concept previously presented is explained. The characteristics of the studied battery are: storage capacity (C) (21 kW h), rated power (P) (3 kW), depth of discharge (DOC) (80%) and full cycle efficiency (η) (70%). To evaluate the economic values from a selected storage, it is necessary to decide a main purpose of the storage then, the calculation of the benefit from its major application and additional returns, from various synergy effects, can be done. In this particular case, all the possible benefits from the use of the storage system are analyzed.

Different aspects have to be considered separately: time shift, services offered to the grid and compensation for reactive power. Finally, the total contribution of them is considered as a whole. To make a numerical quantification of the benefits, the methodology proposed by [47] has been used and adapted to the Spanish energetic system (values for 2013).

Economic benefits of Iron flow battery in the system: Partial economic analysis

Time-shift

In the present framework, time-shift concept represents the benefit based on the time specific prices paid under terms of different tariff prices. The most common practice In the Spain market it is to buy energy according to two different pricing, an off-peak pricing (0.067 €/kW h) and a standard pricing (0.181 €/kW h). The value of the power term in Spain is 1.82443 €/kW/month .With these pricing on mind and the specific characteristics of this battery, the proposed storage battery system gets through this concept a saving of 1.472 €/d.

$$\text{Return}(€/\text{year}) = \text{Saving/day}(€) - \text{Cost/day}(€) \cdot 365 \quad (1)$$

$$\text{Saving/day}(€) = P \cdot C \cdot \text{DOC} \cdot \eta \cdot \text{Standard Pricing} + \text{Power Term}(P/30) \quad (2)$$

$$\text{Cost/day}(€) = C \cdot \text{DOC} \cdot \text{Off Peak Pricing} \quad (3)$$

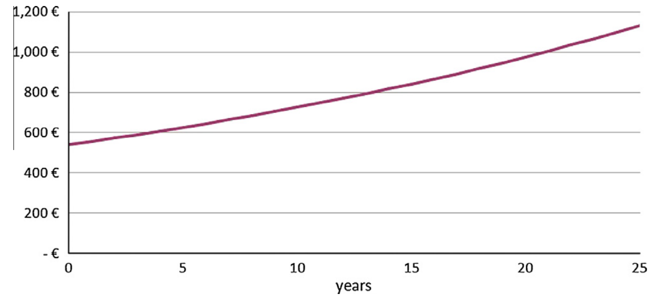

Fig. 4. Temporal evolution of the concept time shifting.

Fig. 4 shows the evolution of this concept throughout the life of the battery, constantly increasing with time. Expression 1 considers this benefit.

Services offered to the grid

This concept includes the investment returns due to: load following, spinning reserves, integration of not controllable power sources and power control.

Load following. It is considered that a system of electrical build-up may be working 2500 h/y in load following service so, for each nominal kW available 2500 kW h/y. can be managed The average price of energy in Spain is taken as references at low pool prices of 20 €/MW h (hydroelectric generation) and at high pool prices of 50 €/MW h (generation in combined cycles). With this price difference, when 2 MW h/y are managed, the returns arises up to 75 €/y/kW based on this service offered (4).

$$\text{Returns}(€/\text{year}) = (\text{High Pool Prices} - \text{Low Pool Prices}) \cdot \text{Energy Managed} \quad (4)$$

Spinning reserves. To evaluate these benefits that the system receives, the service is consider to provide 2500 h to an average price between 3 €/MW h and 6 €/MW h. Maintaining the same assumptions described in the previous concept, annual returns arise up to between 7.5 €/kW/y and 15 €/kW/y obtained in terms of installed rated power (5).

$$\text{Returns}(€/\text{year}) = \text{Energy Prices} \cdot \text{Energy Managed} \quad (5)$$

Integration of not controllable power sources: Nuclear and renewable. A system of batteries that manages 204.4 kW h/kW h/y of energy with the same characteristics previously described are considered. In the Spanish energy mix around half of this energy comes from non-controllable power sources. The cost of managing the grid is the difference between the price that the final consumer pays (0.142 €/kW h) and the pool price (0.05 €/kW h). Operating with all these values, the income that a system of accumulation must obtain for the integration of not controllable power sources it is 4730.43 €/kW h/y (6).

$$\text{Returns}(€/\text{year}) = \text{Energy Managed} \cdot (1-d)^{\text{year}} \cdot r \cdot (1+i)^{\text{year}} \cdot (\text{End User Energy Prices} - \text{Pool Energy Price}) \cdot (1 + \text{Energy Price Increment})^{\text{year}} \cdot l \cdot C \quad (6)$$

- Degradation (d) = 0.5% per year.
- Increment of energy from noncontrollable sources (i) = 2%.
- Rated energy from noncontrollable sources (r) = 0.5.
- Distribution lines (l) = 0.5.

Regulation of power. An annual service of 2500 h/y in this concept is assumed. Therefore each KW manages around 2.5 MW h/y. The cost to manage this energy may be regarded as the cost difference between peak hours and off-peak hours, but at the point of the final consumer. Therefore, according to the Spanish electricity pricing, the benefits under this point are in between 160 €/MW h and 60 €/MW h, which is equivalent to 100 €/W h. This gives as a returns by the regulation power of 250 €/kW/y (7), similar to (4).

$$\text{Returns}(€/\text{year}) = (\text{High Pool Prices} - \text{Low Pool Prices}) \cdot \text{Energy Managed} \tag{7}$$

Fig. 5 shows the value of the returns provided by each of these four concepts throughout the 25 years of battery life.

Compensation for reactive power

In order to quantify this benefit a medium company is considered. On the basis of the information provided, this company can generate about 54 kVarh per kW hired per month. In the Spanish market the compensation when generating a reactive energy with the $\cos\phi$ greater than 0.8 is 0.041554 €/kVarh. With all these data this concept produces savings in penalties and save 46.06 €/kW/y because of the lack of energy purchase (8).

$$\text{Returns}(€/\text{year}) = \text{Reactive Power Generated} \cdot \eta \cdot (0.45 \cdot \text{Standard Pricing} + 0.55 \cdot \text{Low Pricing}) \cdot 12 \cdot \text{DOC} \tag{8}$$

Fig. 6 shows the shape of this temporal evolution of income by this concept.

Integration of total benefits

The weight of the six concepts studied in the previous point regarding the battery global benefit will be analyzed in this section.

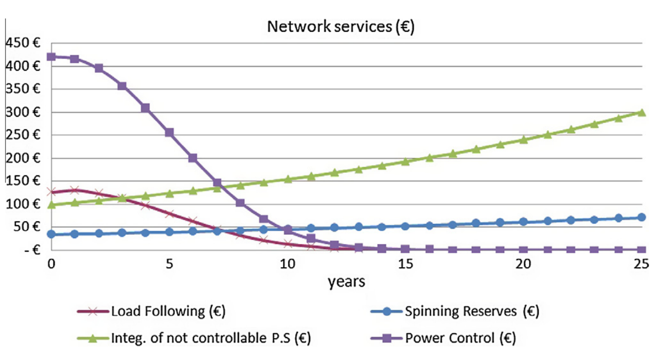

Fig. 5. Value of the returns: load following, spinning reserves, integration of not controllable power sources and the power control.

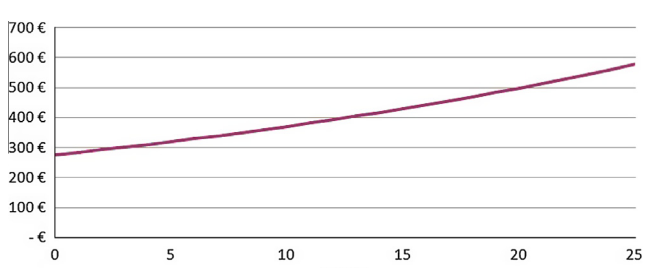

Fig. 6. Income from the concept of compensation for reactive power.

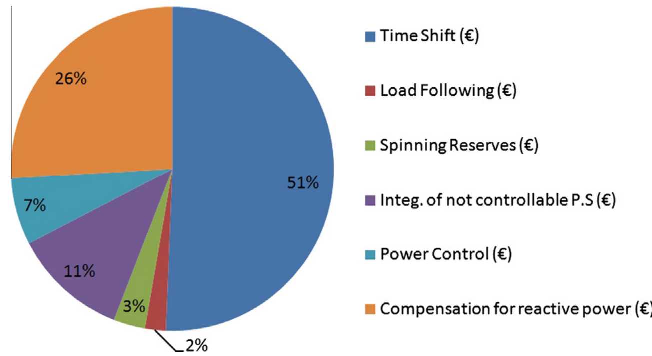

Fig. 7. Integration of different benefits in the total economic balance.

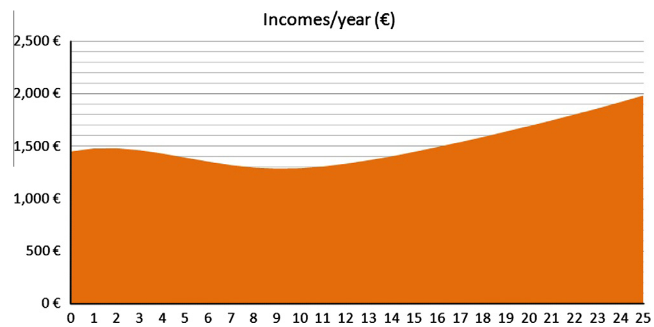

Fig. 8. Incomes per year of the different concepts (Year vs. €).

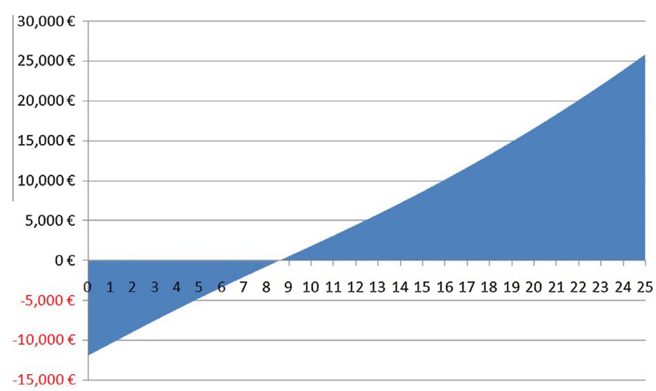

Fig. 9. Cash flow.

As Fig. 7 shows, the greatest economic return is produced by the time shift concept. It contributes more than a half (51%) of all revenues over the 25 years of the battery life. The following more important concept is due to compensation for reactive power which generates 26% of the total benefit. The remaining 23% of the benefits come from the next concepts: load following, spinning reserve, integration of not controllable power sources and power control.

Fig. 8 shows the accumulated returns according to a combination of all concepts analyzed in the previous point. This figure illustrates all the sum of all the considered incomes. These increasing returns are the reason why an electrical accumulation system (in this case, a flow battery in iron base) is economically so convenient.

In Fig. 9 the cash flow is shown. The maintenance costs considered are the consulted references which arise up to 0.008 €/kW h. As it can be observed, a payback of the investment occurs in the eighth year of the battery. Therefore, it is considered an investment

with a very reasonable redeemable deadline. In the present case an IRR of 12% is obtained where the value of the investment is 13,312 € with the specified returns.

Conclusions

In this paper, a general vision of the role played by electrochemical energy storage systems is presented.

It can be concluded, comparing all these possible solutions, that among all of them, iron redox battery is considered as one of the most promising options: according to Table 1, this is the battery with the biggest number of life cycles and the smallest current and future costs. Additionally, this is a long duration battery with a lifespan of approximately 25 years. This is beneficial for long duration applications especially when it must be stored for a long time.

The benefits of the presented alternatives have been depicted focusing on operational and economic aspects. Based on the previously comparative analysis, a particular case study of the iron redox battery has been widely described, particularly applied to Spanish electrical tariff system. As a conclusion, with the applied methodology, the payback of the investment in the battery occurs at the eight year and a half. This is a very reasonable deadline for the return of the investment.

Apart from these economic considerations, electrochemical devices and in particular Iron redox batteries will be of paramount importance in future management of Energetic System.

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